Theoretical analysis and multi-agent simulation of the ecosystem in Tibet

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Abstract

Bird Funeral is a strange funeral custom in Tibet of China. The lamaists hope they can save small fauna such as pikas by sacrificing themselves to the eagles. But can they save the fauna by their sacrifice? By theoretical analysis and multi-agent simulation, we give a negative conclusion that the sacrifice are, in fact, reducing the population of the pikas. In contemporary Tibet, the eagle population is reducing drastically, and the pastures are degenerating. People blame this on the excessive population of the plateau pikas. We propose a model to explain this phenomenon. The eagles are dying off because of overgrazing but not the pikas. We also point out that killing the pikas is probably unhelpful to recover the pastures but worsen the degeneration of the pastures. And if people want to recover the pastures, they have to increase both the population of the predator and the supply of grass simultaneously.

1 Introduction

1.1 A Buddhism Story

Sivika is the king of Devapati City. Sakra is the Indra of the devas, the sky-god, the god of the nature-gods, ruler of the thirty tree heavens. Sakra and another god Visvakarman wanted to test the Attic faith of Sivika. So they transfigured into an eagle and a pigeon. The eagle chased the pigeon into the palace. The pigeon dodged into the king's clothing. So the eagle said to the king: I am

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hungry, I have to eat the pigeon and the pigeon can not escape from me, so please your majesty return it to me. The king said: I will save all emotional life, the exhausted and fearful bird dodged in my clothing, I cant give it to you. The eagle replied: If I have no food, I will die; If you want to save all emotional life, you must save me from starvation. Then the king cut his leg flesh to the eagle. The eagle said: The meat must have the same weight as the pigeon. So the king put the flesh and the pigeon on to a balance, however, the meat was less. The king has to cut more and more, until all meat on legs, arms out, still less, at last the king jumped onto the balance. And Sakra was moved, the earth shook, flower pieces fell from the heaven.

Because of the story above and some other similar Buddhism stories, the Tibetan think that if they sacrifice his/her body to the eagle after their death, they can have a better next-life since it is helpful to save the small fauna. This is the origination of the bird Funeral in Tibet. But are they doing the right thing?

1.2   Ecosystem and Lotka-Volterra Model

Ecosystem is a complex system, no one can tell exactly the role of a certain kind of animal in the system. What's more, the same animal may play different roles under different environments. Here in this paper we will focus on the situation in Tibet.

The environment in Tibet is very different since the Tibetan plateau is largely a treeless environment. The open meadows that constitute the majority part of the plateau make the eco-situation there very different from other parts of the world. The plateau pikas there have been considered as[1, 2] a keystone species for biodiversity on the plateau, based on a review of the natural history and ecology of the pika and those species living in sympatry with it.

But in recent years, the pikas have been blamed for decades as pest for reducing the forage available for domestic livestock and for degrading habitant[3, 4, 5, 6]. And together with the increasing degradation of the grassland over more than 40 years[7], the pikas have become the object of excessive control effort. So in order to control the population of pikas to recover the grassland, people began to poison pikas since 1958 and had escalated greatly by 1962[6]. Is it a right thing to recover the grassland by poisoning the pikas since they play an important role in the ecosystem of Tibet?

The Lotka-Volterra model was first proposed by Alfred Lotka[8] in 1920 to

describe the population dynamics of two interacting species, a predator and its prey. Then in 1926, the very equations was derived by Vito Volterra[9] to describe a hypothetical chemical reaction in which the chemical concentrations oscillate. At the beginning Lotka-Volterra model was proposed as ecological model to describe the closed double-species predator-prey interactions that can be depicted as:

$$\begin{cases} dP/dt = (a - bQ)P \\ dQ/dt = (-c + dP)Q \end{cases} \quad P, Q \geq 0 \tag{1}$$

P is the predator population and Q is the prey population in a closed ecosystem. a represents the natural growth rate of the prey in the absence of predator, b represents the effect of predation on the prey, c represents the natural death rate of the predator in the absence of prey, d represents the efficiency and propagation rate of the predator in the presence of prey. The coupling of PQ indicates the interaction between the two species. Such mathematical models have long proven useful in describing how populations vary over time and have been extended to more than two kinds of species.

1.3 Outline

We give three Lotka-Volterra models in this paper to answer the questions above. In the first model, we explain the phenomena of bird funeral and find that people are doing things with a kind heart but get the opposite result. It means that the bird funeral may leads to the reduction of the population of the pikas. Then why does the population of pikas keep in a high level and the population of eagles reduced much than before? We solve this question in the second model. And in the third model, we point out that killing the pikas is unhelpful to recover the grassland but probably worsen the degeneration of the pasture. And if we want to recover the pasture, we must increase the predator population and the supply of grass simultaneously.

2 Can bird funeral save the pikas?

2.1 Theoretical Lotka-Volterra model analysis

Assume that the system is closed, the food web can be depicted as:
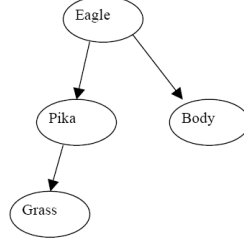
Figure 1: the predator-prey relationship

The Lotka-Volterra equation can be obtained as:

$$\begin{cases} dE/dt = (-a_1 + b_1 R + f_1(B,t))E \\ dR/dt = (a_2 + b_2 G - c_2 E)R \qquad E, R, G \geq 0 \\ dG/dt = (a_3 - b_3 R)G \end{cases} \qquad (2)$$

Where, E is the eagle population, R is the pika population, G is the grass population, a_1 is the death rate of the eagles, b_1 is the rate at which eagles increase by consuming pikas, a_2 is the propagation rate of the pikas, b_2 is the rate at which pikas increase by consuming grass, a_3 is the propagation rate of the grass, b_3 is the rate at which pikas destroy grass, c_2 is the rate at which eagles destroy pikas and $f_1(B,t)$ is the rate at which eagles increase by consuming bodies at time t.

When analyzing the systems of differential equations, it is often helpful to consider solutions that do not change with time, namely, those with $dE/dt = 0$, $dR/dt = 0$, $dG/dt = 0$. Such solutions are called equilibria, steady-states or fixed points.

Equation (2) would achieve equilibrium when

$$\begin{cases} (-a_1 + b_1 R + f_1(B,t))E = 0 \\ (a_2 + b_2 G - c_2 E)R = 0 \qquad E, R, G \geq 0 \\ (a_3 - b_3 R)G = 0 \end{cases} \qquad (3)$$

Equation (3) gives

$$\begin{cases} R = \frac{a_1 - f_1(B,t)}{b_1} \\ E = \frac{a_2 + b_2 G}{c_2} \qquad E, R, G \geq 0 \\ R = \frac{a_3}{b_3} \end{cases} \qquad (4)$$

If $\frac{a_1 - f_1(B,t)}{b_1} = \frac{a_3}{b_3}$, then the equation has a stationary solution. According to the principle of Volterra, $\overline{R} = \frac{a_1 - f_1(B,t)}{b_1}$. If $\frac{a_1 - f_1(B,t)}{b_1} \neq \frac{a_3}{b_3}$, assume that

$\forall t, E, R, G > 0$, the equation is chaotic, we can use the mean of R to measure the equation. Here $\overline{R} = \frac{1}{2}(\frac{a_1 - f_1(B,t)}{b_1} + \frac{a_3}{b_3})$. So if $f_1(B,t) \uparrow$, then $\overline{R} \downarrow$. By coordinate planes analysis, it is very easy to prove that each coordinate plane is invariant[10].

When $\frac{dR}{dt} = 0$, we denote $\overline{R} = R_c$, so (2) gives

$$
\begin{cases}
dE/dt = (-a_1 + b_1 R_c + f_1(B,t))E \\
dR/dt = 0 \qquad\qquad\qquad\quad E, R, G \geq 0 \\
dG/dt = (a_3 - b_3 R_c)G
\end{cases}
\tag{5}
$$

and (5) gives

$$
\frac{dE}{dG} = \frac{\frac{dE}{dt}}{\frac{dG}{dt}} = \frac{(-a_1 + b_1 R_c + f_1(B,t))E}{(a_3 - b_3 R_c)G}
\tag{6}
$$

If we assume $f_1(B,t)$ as a constant, then equation (6) gives

$$
E = KG^{\frac{-a_1 + b_1 R_c + f_1(B,t)}{a_3 - b_3 R_c}}
\tag{7}
$$

(7) gives, if $f_1(B,t) \uparrow$, and if G is invariant, then $\overline{E} \uparrow$. Because $\overline{R} \downarrow$, according to $\frac{dG}{dt} = (a_3 - b_3 R)G, \frac{dG}{dt} \uparrow, \overline{G} \uparrow$. That means bird Funeral is helpful to keep more livestock without changing the environment much.

From the theoretical analysis above we can get the conclusion that the bird funeral custom could not save the pikas, but on the contrary, it makes a lot of pikas die of the increasing eagles.

2.2 Multi-agent simulation

We also use multi-agent model to simulate the ecosystem above. In our model, some simple rules are given: 1. The eagle and the pika move at random and this movement consumes energy. 2. The eagle and the pika will die when they don't have enough energy. 3. When the eagle meets the pika, the eagle will eat the pika and increase the eagle's energy. 4. The eagle and the pika can reproduce themselves and their offspring will have 1/2 of the parent energy. 5. When the pika meet the grass, the pika will eat the grass and increase the pika's energy. 6. The grass can reproduce at intervals. 7. The bodies appear at fixed positions at intervals.

We use Netlogo to do the simulation. At the beginning, the number of bodies is 0, then, after the number of pikas achieves equilibrium, we set the number of bodies a positive number. We define the average population of every species as:

$$
Apopulation = \frac{\sum_{t=1}^{N} population}{N}
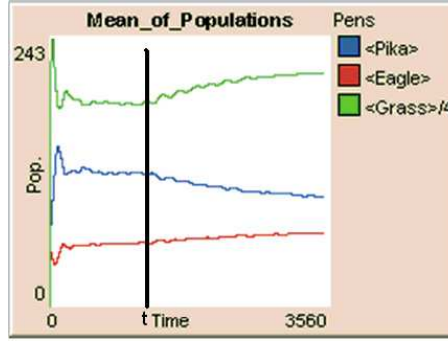\tag{8}
$$

Figure 2: the change of the average population when bodies increase

Fig.2 is the change of the average population when the number of bodies increase. We can see that the population of pikas are reducing with the increasing of the number of human bodies. The reason is that the human bodies will nurture more eagles, and the increased eagles will eat more pikas. And with the reduction of pikas, the grass will flourish.

But why are the population of pikas are increasing in Tibet now? And in fact the population has increased so much that people have to control it artificially.

3 Who is the killer of the eagles or the protector of the pikas?

It is commonly accepted that[2] the plateau pika of the QingHaiCXiZang(Tibetan) plateau, Peoples Republic of China, have been considered to be a kind of pest because they have such a big population that they compete with native livestock for forage and contributes to pasture degradation[3, 4, 5, 6]. What is more, simultaneously, the eagle population is reducing drastically so that some Tibetan have to abandon the traditional custom of bird funeral but chooses some other kinds of funeral, e.g. cremation. Why the population of eagles is decreasing with an abundant food from pikas? Who is the killer of the eagles and the protector of the pikas?

3.1 Theoretical Lotka-Volterra model analysis

In fact, if we include the influence of livestock, the system will not work in the simple way as we think. Take the influence of livestock, the ecosystem can be
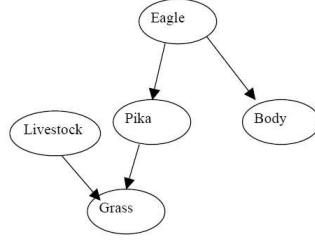
depicted as:

Figure 3: The Predator-Prey Relationship

Including the livestock, the differential equation of the ecosystem in Tibetan can be written as:

$$\begin{cases} dE/dt = (-a_1 + b_1 R + f_1(B,t))E \\ dR/dt = (a_2 + b_2 G - c_2 E)R \qquad E, R, G \geq 0 \\ dG/dt = (a_3 - b_3 R - f_3(L,t))G \end{cases} \qquad (9)$$

Where $f_3(L,t)$ is the rate at which the livestock destroy the grass at time t.

Equation (9) has ever been discussed in[10]. If $\frac{a_3 - f_3(L,t)}{b_3} < \frac{a_1 - f_1(B,t)}{b_1}$, the eagle will die out, and if $\frac{a_3 - f_3(L,t)}{b_3} > \frac{a_1 - f_1(B,t)}{b_1}$, the eagle will survive and grow without boundary. And the pika simply act as a conduit between the top and bottom species.

The real world ecosystem is quite stable relative to human life, so we can assume that $\frac{a_3 - f_3(L,t)}{b_3} = \frac{a_1 - f_1(B,t)}{b_1}$. Then if $f_3(L,t) \uparrow$, $\frac{a_3 - f_3(L,t)}{b_3} < \frac{a_1 - f_1(B,t)}{b_1}$, the population of the eagle will decrease and when $t \to \infty$, $E \to 0$, but the population of the pikas won't change much since it is just a conduit. But once $E = 0$, the system will degrade into the common Lotka-Volterra Equation, which implies $R \uparrow$.

3.2 Multi-agent simulation

We revise the multi-agent model of bird funeral to solve this problem by adding three new rules: 1. The livestock eat the grass. 2. The livestock move around randomly. 3. The livestock will not die in the ecosystem without live human.

We can see from Fig.4 that the eagle population will decrease with the increase of the livestock, so maybe it was the increasing of the livestock that caused the dying of the eagles. And when the eagles die out, the population
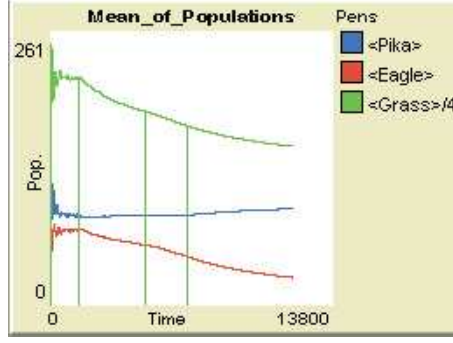
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Figure 4: the change of the average populations when overgrazing

of pikas will increase. However, according to the actual situation in Tibet, is it the right thing to recover the grassland by poisoning pika?

4   Are they doing the right thing?

Poisoning of pikas began in 1958 and had escalated greatly by 1962[6]. Till now rodenticide are applied greatly to control the rodent density. Zhibin Zhang et al.[11] thought that the management of livestock is very important for rodent control because overgrazing is the major factor of causing serious rodent infestations. In Qinghai, plateau pikas and zokors can be controlled effectively by rodenticide, followed by the use of herbicides to control weeds and exclosures to reduce grazing by livestock, and then re-planting of grass. It is oblivious that the reduction of grazing by livestock will increase the population of the eagle, but it won't change the population of the pikas much. But if the eagles die out, this will increase the population of the pikas.

Then what is the influence of the poisoning of the pikas?

4.1   Theoretical Lotka-Volterra Model Analysis

Take the influence of the poison into consideration, the ecosystem can be depicted as:

We can obtain the differential equation of Fig.5 as:

$$
\begin{cases}
dE/dt = (-a_1 + b_1 R + f_1(B,t))E \\
dR/dt = (a_2 + b_2 G - c_2 E - f_2(P,t))R \quad E, R, G \geq 0 \\
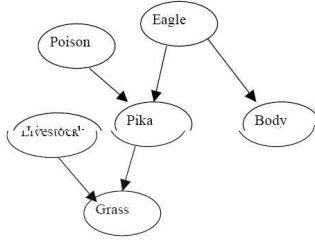dG/dt = (a_3 - b_3 R - f_3(L,t))G
\end{cases}
\tag{10}
$$

8

Figure 5: The Predator-Prey Relationship

$f_2(P,t)$ is the rate at which people poison the pikas. Equation (10) achieves equilibrium when

$$\begin{cases} (-a_1 + b_1 R + f_1(B,t))E = 0 \\ (a_2 + b_2 G - c_2 E - f_2(P,t))R = 0 \quad E, R, G \geq 0 \\ (a_3 - b_3 R - f_3(L,t))G = 0 \end{cases} \quad (11)$$

(11) gives

$$\begin{cases} R = \frac{a_1 - f_1(B,t)}{b_1} \\ E = \frac{a_2 + b_2 G - f_2(P,t)}{c_2} \quad E, R, G \geq 0 \\ R = \frac{a_3 - f_3(L,t)}{b_3} \end{cases} \quad (12)$$

If $f_2(P,t) \uparrow$, $E \downarrow$. And if $E = 0$, $\overline{R}$ will increase drastically. That means poison the pikas equals poison the eagles, which will cause quicker increase of the pikas with the decrease of the eagles.

4.2 Multi-agent Simulation

We revise the multi-agent model of overgrazing to solve this problem by adding one new rule: pikas can be killed at intervals.

We can conclude from Fig.6 that poison pikas can reduce the population of the eagle. But after the population of the eagle decrease to a certain small value, the population of the pika will increase faster. It means that, if we want to keep the pika in a low density by using rodenticide, we have to use increasing rodenticide, otherwise, the pika will boom and compete with the livestock. This is in accordance with the conclusion of the theoretical analysis.
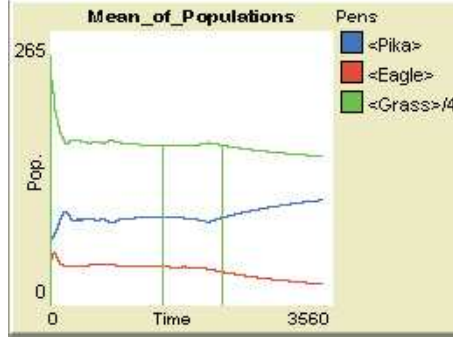
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Figure 6: the change of the average populations when poisoning pika

5   conclusion

In this paper we discuss the ecosystem in Tibet by theoretical analysis and multi-agent simulation. We begin with the discussion of the impact of Bird Funeral on the environment of Tibet and get the conclusion that bird Funeral is helpful to keep more livestock without changing the environment much though it can not save the fauna. Then we discuss the environmental impact of over-grazing; overgrazing can cause the extinction of the eagles, which means that, to a certain extent, the livestock is the predator of eagle. Thirdly we discuss the environmental impact of poisoning pikas, we conclude that this human behavior will extinct the eagle population.

What is more, from the discussion on the reduction of eagle species, we can conclude that the ecosystem has two phases, if $E > 0$, the increase of grass will lead to the reduction of pikas, but if $E = 0$, the pika population will increase. So if we want to recover the pasture, we must increase the supply of grass on one hand and make $E > 0$ on the other hand. Moreover, we must be cautious that we should make $\frac{a_3 - f_3(L,t)}{b_3} \geq \frac{a_1 - f_1(B,t)}{b_1}$.

We also give out some suggestion according to the actuality in Tibet for the Tibetan to recover their grassland to protect the balance of the nature.

Indeed the real-world ecosystems are more complex than the considered models above. Here we just present some of our toy models of the ecosystems. We hope we can do some more work on it in the future.

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